

FINAL TECHNICAL REPORT FOR NAG 5-7971
for Columbia University

Submitted to: Dr. Ronald J. Oliveresen
Mail Code 681
Building 21, Room 036
NASA/Goddard Space Flight Center
Greenbelt, MD 2077

Submitted by: The Trustees of Columbia University
in the City of New York
351 Eng. Terrace
New York, New York 10027

Prepared by: Columbia Astrophysics Laboratory
Departments of Astronomy and Physics
Columbia University
550 West 120th Street, MC-5247
New York, New York 10027

Principal Investigator: Karen Leighly

Title of Research: Narrow-Line Seyfert 1 Galaxies

Report Period: 9/15/99 – 9/30/00

Columbia University in the City of New York | *New York, NY 10027*

DEPARTMENTS OF ASTRONOMY AND PHYSICS
Columbia Astrophysics Laboratory

550 West 120th Street
Mail Code 5347
Tel: 212-854-3257
Fax: 212-854-8121

July 31 2000

Dr. Ronald J. Oliversen
Mail Code 681
Building 21 Room 036
NASA Goddard Space Flight Center
Greenbelt, MD 20771

Dear Dr. Oliversen,

This letter represents part of my progress report and annual continuation proposal for the LTSA grant **NAG5-7971** entitled “**Narrow-Line Seyfert 1 Galaxies**,” which began on 9/15/98. The objectives of this proposal are to understand the nature of the emission from the Narrow-line Seyfert 1 class of galaxies through a comprehensive program of space and ground based observations as well as modeling. Starting August 16 2000, I will take a position as assistant professor in the Department of Physics and Astronomy at the University of Oklahoma. Columbia University will deobligate the grant so that it can be transferred to OU. Therefore, this annual report will serve as my final technical report for Columbia University. The new budget will be submitted from OU shortly.

A. Results from the Preceding Year

The primary work during this year has been the analysis and interpretation of our HST spectra from two extreme Narrow-line Seyfert 1 galaxies (NLS1s) IRAS 13224–3809 and 1H 0707–495. This work has been presented as an invited talk at the workshop entitled “Observational and theoretical progress in the Study of Narrow-line Seyfert 1 Galaxies” held in Bad Honnef, Germany December 8–11, as a contributed talk at the January 2000 AAS meeting in Atlanta, Georgia, and as a contributed talk at the workshop “Probing the Physics of Active Galactic Nuclei by Multiwavelength Monitoring” held at Goddard Space Flight Center June 20–22, 2000. The paper entitled “HST STIS Ultraviolet Spectral Evidence of Outflow in Extreme Narrow-line Seyfert 1 Galaxies”, K. M. Leighly & J. P. Halpern is now in preparation and should be submitted within the next month.

The principal observational result is that the high-ionization lines, including C IV, Ly α , N V and Si IV are much broader than the low ionization lines including Mg II and H β . While the trend for high ionization lines to be broader than low ionization lines has been known previously, these spectra show an extreme of this phenomenon. Furthermore, the

high-ionization lines are strongly blueshifted; they have nearly no emission to the red side of the rest wavelength. Again, the tendency for the high ionization lines to be blueshifted compared with the low ionization lines has been known before, but these spectra show the extreme of this phenomenon. The observational results are most simply compatible with the interpretation that the emission lines are produced in a disk-wind system: the high-ionization lines are produced in a wind coming off the disk, probably accelerated by resonance-line driving as is inferred in CVs and hot stars, and the low ionization lines are produced in the low velocity material at the base of the wind or in the disk itself. The disk is optically thick, so emission is only seen from the wind coming toward us; hence the strong blueshifts imply terminal velocities greater than 10,000 km/s.

This result seems to be of fundamental importance for AGN research. The broad optical emission lines in AGN have been studied for many years, but despite this intensive effort, the basic geometry of the line emission has not yet been determined. A number of models have been proposed, including the disk-wind model outlined above, but these are the first spectra that seem to support that model unequivocally. This result may be important for the understanding of NLS1s, because it may support the prevalent model that NLS1s are characterized by a high accretion rate. If the accretion rate is high relative to the black hole mass, the escape velocity is relatively lower and the radiation pressure is relatively higher, and thus a high velocity wind is more likely to be formed. This scenario may explain another observational result. We find that the Si III] to C III] ratio is very large in these objects. These emission lines are produced under similar photoionization conditions, but C III] has a smaller critical density. The high densities $> 10^{10} \text{ cm}^{-3}$ in the accretion disk are expected also if the accretion rate is high.

The qualitative interpretation of our data is relatively straightforward, but a more quantitative investigation of the spectra leads to a deeper understanding of the phenomenon. We are pursuing several lines of investigation. First, we ask the question, can we understand something about the nature of the wind through an examination of the line profiles and ratios? We developed a template for the emission of wind from the C IV line and used it to fit the other high ionization lines. In CVs and hot stars, the high velocity material is not thought to emit the lines but rather only scatter continuum photons by resonance scattering. In contrast, we found that in these AGN, primary emission must be occurring, because there is good evidence that O IV, a line with small cross section for resonance scattering, is present in the wind. However, we found that we cannot tell yet whether the high ionization lines all have the same profile. If this were the case, it would imply that the wind emission is relatively localized. Recent detailed magneto-hydrodynamic dynamical models predict that instabilities may cause regions of enhanced density and thus may support this scenario. Alternatively, the wind could be extended, in which case lines occurring typically from higher ionization states may be expected to be stronger. Such distinction will have to wait until we observe the O VI line either from these objects using *FUSE* or higher redshift, similar objects using *HST*.

We are also trying to understand the density and ionization state of the line emission using the photoionization code *Cloudy*. We find that it is probably not possible to produce the observed emission line ratios if the line emitting gas sees the same continuum we see. The caveat to this statement is that results from *Cloudy* simulations may not be completely applicable to these spectra, as the radiation transfer in the wind can be strongly modified

if velocity shear exists in the flow. Physically, however, it is quite possible that the line emitting gas may not see the same emission that we do. First, there is evidence that the high amplitude X-ray variability observed in NLS1s is amplified by beaming, thus the line emitting gas may not see nearly as strong soft X-ray emission as we see. Second, dynamical models for winds driven by resonance line scattering require that the soft X-rays be removed in order that high velocity winds be produced; otherwise, the optically thin gas becomes too highly ionized. In the dynamical models, the absorption may occur in gas that was originally accelerated but became too highly ionized and starts to fall back into the nucleus. Removal of the soft X-rays affects the emission lines in two ways: first, several the atoms producing strong emission lines that we see, namely aluminum and silicon, have significant L-shell photoionization cross-sections with ionization potential occurring in the soft X-rays. Second, the soft X-rays contribute a strong source of heat. We are now quantifying these results.

We also have a substantial effort to explicitly model the emission lines using a simplified disk-wind model. We adapt our model from a disk-wind model previously developed by Murray & Chiang (1998): we assume that the kinematics are described by a beta velocity law, commonly used in modeling hot stars and CVs, and the original Keplerian velocity of the disk is also included. However, we are interested in the emission from the wind, so we treat the radiative transfer numerically using the Sobolev approximation. We have computed line profiles, assuming a homogeneous ionization structure, and find that we can obtain blueshifted profiles for relatively low observer inclination angles. We are now in the process of including the ionization structure using *Cloudy*. This is a bit tricky because *Cloudy* performs its own radiative transfer and thus we must compute the photoionization in a large number of radial and azimuthal zones.

We try to place the results in context by comparing our line profiles with those from 15 other NLS1s in the *HST* archive. We find a very interesting result: the degree of asymmetry in the emission line is inversely correlated with the line equivalent width. Our tentative interpretation of this result is that perhaps all NLS1 high ionization lines, and perhaps all quasar lines in general, contain a highly blueshifted component from a wind. Then, most objects, excluding our objects, also have a symmetrical component centered at the rest wavelength, possibly emitted by the low velocity gas at the base of the wind or the disk. We speculate that the reason that we don't see this component in our galaxies is because the wind is so thick that the low velocity gas is shielded. Our objects show the most extreme X-ray characteristics, i.e. the highest amplitude of variability and the strongest soft X-ray excess component. We speculate that all NLS1s have a high accretion rate compared with Seyfert 1 galaxies with broad optical lines; however, our objects and a few others that show very high amplitude flaring X-ray variability are characterized by an ultra-high accretion rate approaching the Eddington values, where accretion onto a black hole may be quite unstable.

Another significant accomplishment during the last year was the organization of the workshop mentioned above "Observational and theoretical progress in the Study of Narrow-line Seyfert 1 Galaxies" held in Bad Honnef, Germany December 8–11. I was a member of the scientific organizing committee for this small and focused workshop. Many of the most important workers in this field were among the 75 participants. The workshop was very successful, stimulating exciting discussions. I was also one of the four editors of the pro-

ceedings which will be published by New Astronomy Reviews. The book is now in press and will appear in September.

I also have a paper nearing completion with Dirk Grupe and H.-C. Thomas on an NLS1 RX J2217–59. This NLS1 was bright during the *ROSAT* All Sky Survey and was picked up as part of the soft X-ray selected AGN sample. However, in subsequent *ROSAT* HRI and *ASCA* observations, it was very faint. The *ASCA* observation was rather difficult to analyze and the results are somewhat uncertain due to the presence of two other bright objects 4 arcminutes from the AGN. However, it seems clear that the *ASCA* spectrum is steep, as one would expect if the source has become fainter, rather than being hard, as it would be if the spectrum had become absorbed.

A related paper is in preparation on a comparison of the variability properties of 3C 390.3 and Fairall 9. These two objects have approximately the same luminosity and approximately the same X-ray variability properties on time scales of one day. However, on long time scales the variability properties are different: the power spectrum of Fairall 9 as observed using *RXTE* is much flatter than that of 3C 390.3. We suspect that this is somehow related to the accretion processes in these objects. Several characteristics of 3C 390.3 have led to speculation that this object is accreting through an Advection Dominated Accretion Flow (ADAF) rather than the classical slim disk. We speculate that the differences in the slopes of the variability power spectra are related to the accretion.

Finally, I am working with a Columbia University graduate student, Miranda Jackson, on a series of coordinated *RXTE* and *ASCA* observations of a luminous Seyfert 1 galaxy Mrk 509. The purpose of the observation was to look for variability in the Compton reflection component recognized above ~ 10 keV in a number of Seyfert 1 galaxies. We discovered variability in the reflection implying that the material reflecting the X-rays occurs fairly close to the central engine.

Bibliography

RX J2217.9-5941: A highly X-ray variable Narrow-line seyfert 1 Galaxy

D. Grupe, H. C. Thomas, & K. M. Leighly, in preparation (to be submitted to A&A)

RXTE/ASCA Monitoring Observation of the Luminous Seyfert 1 Galaxy Mrk 509

M. Jackson, K. M. Leighly, & M. Matsuoka, in preparation (to be submitted to The Astrophysical Journal)

ASCA (and HST) Observations of NLS1s

K. M. Leighly, in Proc. "Observational and theoretical progress in the study of Narrow-line Seyfert 1 Galaxies", ed. T. Boller, W. N. Brandt, K. M. Leighly & M. Ward, to be published by New Astronomy Reviews, Sept. 2000

HST STIS Ultraviolet Spectral Evidence of Outflow in Extreme Narrow-line Seyfert 1 Galaxies

K. M. Leighly & J. P. Halpern, in preparation (to be submitted to The Astrophysical Journal); also Proc. "Probing the Physics of Active Galactic Nuclei by Multiwavelength Monitoring", June 20–22 2000, GSFC

Long-term X-ray Variability from the Luminous AGNs Fairall 9 and 3C 390.3

K. M. Leighly, M. Jackson, M., J. P. Halpern, M. Eracleous, & R. A. Remillard, in preparation (to be submitted to The Astrophysical Journal)

B. Work in Progress and Research Plans for the Coming Year

There are several major projects planned for the coming year. We have recently received the data from our simultaneous *FUSE*, *ASCA* and *EUVE* observation of the NLS1 RE 1034+39. The data from the *Chandra* observation of Ark 564 has also arrived, and the *Chandra* observation of 1H 0707–495 will be done this September. Long observations of several NLS1s using *ASCA* have been performed. There are a number of things to be done, and our first efforts will be on the following:

1. Our *HST* observations described above require some follow-up observations. Specifically, we want to try to understand the wind geometry and emission. The key will be to observe the O VI λ 1034 emission line. It is predicted to occur in regions characterized by higher ionization than C IV. Ideally we could get some clue about what is going on from the N V line; however, the blue side of that line falls under the Ly α line that is also broad, and thus it is too severely blended to get very much information from it. If the O VI line has a significantly broader or different profile than the C IV line, we may expect that the wind emission should occur from an extended region with ionization stratification. Alternatively, if the line profiles are nearly the same, we will suspect that the wind emission occurs in a localized region where the conditions are just right. Recent dynamical modeling that this could be the case. We have already submitted a *FUSE* proposal to observe the objects that we have *HST* spectra from; these objects have relatively low redshift and the O VI emission line is not observable by *HST*. We also plan to submit an *HST* proposal to observe two objects with higher luminosity and higher redshift. We also plan to continue working on the kinematic wind model described above. We expect that comparison of the data with the results of the model will help us understand whether the wind is smooth or whether there should be clumping, whether resonance line-driving is adequate to accelerate the emitting wind, whether radiative transfer of the lines in the wind plays an important role in determining the line profile, and ultimately how much continuum scattering contributes to the lines.
2. We plan to further investigate the X-ray variability characteristics of NLS1s that were started in Leighly (1999). We proposed for and were awarded a long *ASCA* observation of one of these extreme NLS1s IRAS 13224–3809. The observation was to have been three weeks long; a little bit more than a week of data was obtained before *ASCA* recently went into safe-hold mode, as condition that it has not recovered from. Indeed, this may have been *ASCA*'s last observation. We plan to use these data as framework around which to build an investigation of AGN time series analysis. Our plan is to construct simple models for AGN variability, produce simulated light curves with the same sampling properties and noise characteristics as obtained by *ASCA* and then employ sophisticated data analysis techniques to try to differentiate between models. The results will be used to try to constrain variability models for NLS1s. This will be the primary

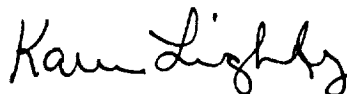
large effort for this fall.

3. A new bright quasar was discovered in the FIRST radio survey. This object, with $V=13.9$ and $z=0.181$, is the second brightest quasar known beyond $z=0.1$. Interestingly, it has a NLS1 optical spectrum and *no* detectable X-ray emission in the *ROSAT* All Sky Survey. To try to understand this extreme object, we have several observations made or planned. We have observed this quasar with *BeppoSAX* on May 16; however, because of the staffing problems at the *BeppoSAX* Science Center, we have not yet received the data. We are working with the *FUSE* GTO team, who wanted to observe it to look for Deuterium. In exchange for the position of the quasar, they will allow us to analyze the spectra. We have proposed for *Chandra* and *HST* time to observe this quasar as well.
4. With the Lick runs in January and April 2000, we have completed a substantial collection of new spectropolarimetric observations of NLS1s and preliminary results show that we have discovered several new objects with significant polarization. The polarized objects will be examined and selected for suitability for followup *HST* and *Chandra* or *XMM* observations to investigate absorption in these objects.

C. Budget

This report is the terminal report for Columbia University and therefore no budget is attached. A budget will be submitted from the University of Oklahoma separately.

Sincerely yours,



Karen Leighly
Associate Research Scientist
email: leighly@astro.columbia.edu
telephone: 212-854-6892